Appendix A

USE OF THE QUASI-STATIC MODEL TO ESTIMATE POTENTIAL SPALLINGS RELEASES ASSOCIATED WITH AN INADVERTENT INTRUSION INTO THE WIPP REPOSITORY BY AIR DRILLING

INTRODUCTION

This appendix describes a preliminary approach to estimating the consequences of an inadvertent air drilling intrusion into WIPP using one of the analytical tools (i.e. the quasi-static model) developed by DOE to calculate the volume of spallings which might be released. The quasi-static model is described in the Sandia National Laboratories report on spallings (Docket A-93-02, Item II-G-23). In this model, gas flow in the porous waste is approximated by a series of steady state profiles at various times after the waste is intercepted by a drill bit. The model calculates the rate at which the drilling mud is driven from the borehole and the attendant changes in bottom-hole pressure. The pore pressure gradient and the bottom-hole pressure are used to determine the stresses in the waste.

The quasi-static model employs two EXCEL spreadsheets to perform the required calculations. Spreadsheet P145APCK.xls is used to calculate the bottom-hole pressure, p_o, and the time-varying radial boundary, R(t), of a hemispherical cavity at which the pore pressure, p(r), equals the far-field pressure, p_1. Spreadsheet S145APCK.xls utilizes the values of R(t) and p_o at various times to calculate the stress profiles in the waste. Waste is assumed to fail outward from the borehole wall to any radial point at which the stress in the waste exceeds the waste strength. Although S145APCK.xls includes equations for both tangential and radial stresses, calculated failures involve only tensile radial stresses. Thus, the failure radius is the point at which the radial tensile stress equals the tensile strength of the waste. The quasi-static model does not address the extent to which this failed volume of material is transported to the surface. (All of the material is conservatively assumed to be released.)

Typical parameters used in P145APCK.xls include (*ibid*., Table 3-1, p. 3-16):

- Permeability (k) - 1.7×10^{-13} m^2
- Porosity (ϕ) - 0.7
- Far-field pressure (p_1) - 14.5 MPa
- Mud density - 1211 kg/m^3
- Mud viscosity - 0.00917 Pa•s

Assuming a waste tensile strength of 0.06897 MPa (10 psi), the failed radius in the waste is 0.36 m and the comparable uncompacted failed volume (*ibid*., p. 3-32) is 0.19 m3. The uncompacted failed volume is directly equivalent to the spallings volumes reported in the CCA (*ibid*., p. 3-22). In this example, blowout (mud ejection from the borehole) occurred 84 seconds after the intrusion, at which time the bottom-hole pressure was 4.8 MPa.

In order to modify the spreadsheet to assess air drilling impacts, the "drilling mud" was assigned the properties of air rather than brine. Assuming that the pressure of the air drilling fluid delivered to the bottom of the borehole is 15 atm (1.52 MPa), the density of the air is 17.6 kg/m^3, based on an air density of 1.2929 kg/m^3 at 1 atm and 0^{o}C (*Handbook of Chemistry and Physics,* 36th edition, p. 1948). Spreadsheet P145APCK.xls assumes that the brine drilling mud is an incompressible fluid which is not the case with air drilling. To approximate the situation where the drilling fluid is a compressible gas, the air density was averaged over the borehole length at 9.4 kg/m^3 ([17.6+1.3]/2). The waste permeability was set at 2.4x10^{-13} m^2-- the value used in the PAVT. The air viscosity was assumed to be 18.2x10^{-6} Pa•s (*Handbook of Chemistry and Physics,* 36th edition, p. 2009) . The time steps were adjusted near the time at which blowout occurred by reducing the time interval to 0.01 seconds. No other changes except minor re-formatting to facilitate spreadsheet usage were made.

RESULTS

Calculations are summarized in spreadsheets P145APC4.xls and S145APC4.xls. For the air drilling simulation, blowout of the air column occurred in 9.1 seconds at which time the bottom-hole pressure had fallen from 14.5 MPa to 1.07 MPa. The variation of bottom-hole pressure with time is shown in Figure 1.

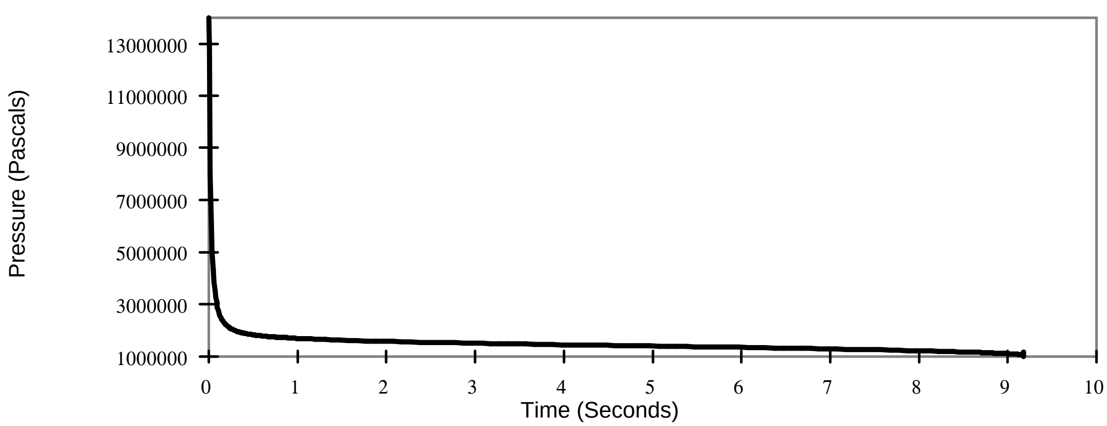

Figure 1 Cavity Pressure

Figure 2 presents the radial stress distribution at various times. For times greater than one second it can be seen that a band of compressive stresses exists at the borehole wall which prevents tensile failure. (Compressive stresses are positive.) For times of 0.01, 0.10, 0.20, 0.50 and 1.00 second, a tensile zone exists near the borehole wall. The maximum radius of material which had failed in tension (at 1 second) was 0.69 m, which translates to an uncompacted volume of 1.38 m^3.

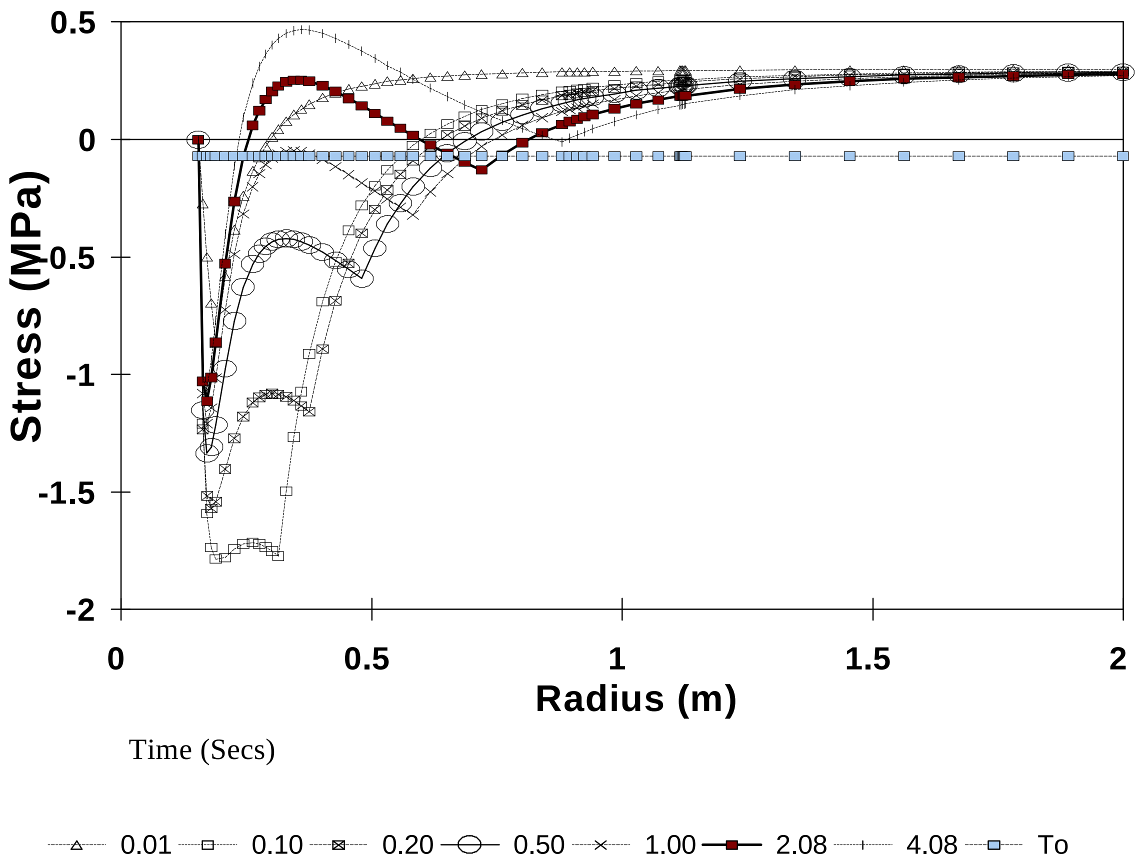

Figure 2--Effective Radial Stress

As noted above, the approach taken here to approximate blowout conditions was to assume an average density for the compressible drilling fluid. To test the sensitivity of the results to this assumption, runs were made where the average air density was decreased to 4.4 kg/m^3 and increased to 14.4 kg/m^3. At the lower air column density, the uncompacted failed waste volume was 1.42 kg/m^3, while at the higher density, the failed volume was 1.36 m^3, thus indicating that the results are not particularly sensitive to air density variations of about ±50%.

Based on Replicate 1 of the CCA, only 9 of 100 realizations exhibited pressures of 14.5 MPa or greater. For the remaining realizations the failed volumes would be less than the levels cited above. In the event that multiple intrusions into the repository occur, the pressure at the time of the second and additional intrusions will be substantially lower than for intrusion into the undisturbed repository, as shown in Helton and Jow, 1996 ("Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 Compliance Certification Application for the Waste Isolation Pilot Plant," Docket: A-93-02, II-G-7). It can be seen from

Figure 3.3.1 of that document that after a few hundred years from the time of intrusion, the pressure does not exceed 12 MPa for any of the Replicate 1 realizations.

Based on this modeling, it does not appear that the quantities of material spalled from the waste during air drilling will significantly alter the spallings volume estimates included in the CCA and the PAVT (i.e., 0.5 to 4.0 m^3). In addition, this modeling approach treats blowout as a slug flow process in which the air column is driven from the borehole by waste-generated gas (e.g., hydrogen). It is likely that significant mixing of the gases will occur as the air column transits the borehole. However, as noted above, the results are not very sensitive to the gas density, so gas mixing is likely to be a second order effect.